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THE SILTING OF CAONILLAS RESERVOIR PUERTO RICO

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A cooperative study by the Soil Conservation Service, United States Department of Agriculture, and the Department of Agriculture and Commerce, Commonwealth of Puerto Rico

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THE SILTING OF CAONILLAS RESERVOIR, PUERTO RICO

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ABSTRACT

The Caonillas Hydroelectric Project was completed in 1948 by the Puerto Rico Water Resources Authority. The reservoir is located 4½ miles east of the town of Utuado. The original storage capacity of the reservoir was 50,149 acre-feet, largest in the Island. The 48.9 square-mile watershed is situated in the mountainous interior of west central Puerto Rico. The Caonillas Extension Project, which went into operation during October 1952, has increased the watershed area to 85.5 square miles. Average rainfall is about 85 inches, and runoff 34 inches annually.

A total of 266 acre-feet or sediment had washed into the lake during 4.3 years of storage, an average annual storage loss of 61.8 acre-feet. Sediment was being deposited in the reservoir at an average rate of 1.29 acre-feet per year per square mile of drainage area. Average dry weight of the sediment samples was 38.1 pounds per cubic foot. The samples averaged 30.59 percent sand, 53.85 percent silt, and 15.56 percent clay. At the present rate of sedimentation the useful life of the reservoir is estimated at about 275 years.

Sheet erosion on the steep agricultural lands is the principal source of sediment. The annual soil loss from erosion is estimated at 61,800 tons, 24.4 percent of which comes from cultivated land, 21.2 percent from pastures, 40.5 percent from coffee lands, and 13.8 percent from woodlands. Clean-tilled land, which occupies only 3.3 percent of the total land area, is the source of 22.8 percent of the soil lost by erosion.

Improved land use and treatment practices offer the best solution to the sedimentation problem. These measures should include conversions to less intensive use, improved rotations, contour cultivation, strip cropping, crop residue management, vegetative and rock barriers, water-disposal systems, and fertilizing and liming. The acreage of improved pasture, well managed coffee land, and woodland should be increased and the acreage of cultivated crops decreased. It is estimated that erosion losses can be reduced 80 percent by a complete conservation program.

INTRODUCTION

The purpose of this study was to determine the rate of storage loss in Caonillas Reservoir resulting from soil and other erosional debris washing into the lake; to determine the principal sources of this material; and to make some broad recommendations for reducing the rate of sedimentation. The study included a detailed sedimentation survey of Caonillas Reservoir and a detailed soil conservation survey of the watershed. The sedimentation survey was conducted as part of the Caonillas Watershed Management Program of the Puerto Rico Department of Agriculture and Commerce. The study was made by the Southeastern Region of the Soil Conservation Service in cooperation with the Puerto Rico Department of Agriculture and Commerce. Field work on the sedimentation survey was done during October and November 1952.[1] The soil conservation survey of the watershed was made by the Soil Conservation Service to obtain the physical information needed for determining sediment sources and soil conservation practices. Descriptive material on the Caonillas Hydroelectric Project and hydrologic data were obtained from the Puerto Rico Water Resources Authority.

Sediment is a product of erosion. Its movement is governed by topography, stream characteristics, rainfall, and streamflow. The amount of sediment delivered to any point in a stream system depends largely on the amount of erosion in the watershed and the ability of the drainage system to transport this eroded material. The rate of erosion depends on the inherent erodibility of the soils, land use conditions, length and steepness of slopes, and the intensity, duration, and frequency of rainfall. In Puerto Rico, sheet erosion on agricultural lands is the only important source of sediment.

The ability of a reservoir to retain sediment depends on the length of time water is retained in storage. The longer water is held the more opportunity there is for sediment to settle to the bottom. Sediment carried by a stream settles out as the velocity of the current decreases. When the stream enters the pool behind the dam, stream velocity is dissipated and decreases almost to zero. The coarse sediments settle out immediately. The finer sediments gradually settle to the bottom as the water completes its slow movement through the reservoir.

The useful life of a reservoir is determined by the rate of sedimentation in relation to the amount of storage capacity required as reserve to assure operation during periods of low flow. Progressive loss of capacity from sedimentation brings this reserve, or carryover storage, nearer to the critical point where it will be insufficient to meet requirements during periods of low inflow.

Information on reservoir silting in Puerto Rico is limited. Data available from several estimates and studies of individual

[1] Field work by John J. Noll, Geologist, Soil Conservation Service; Angel H. Quintero and Pablo Velazquez-Walker, Agronomists, Puerto Rico Department of Agriculture and Commerce; assisted at various times by L. C. Gottschalk, Research Specialist; Juan P. Cordova, Supervisory Soil Scientist, Soil Conservation Service, and other personnel of the Soil Conservation Service and the Puerto Rico Department of Agriculture and Commerce.

reservoirs show some unusually high rates of sedimentation. Reservoir capacities and the factors affecting erosion, transportation, and deposition of sediment differ widely and result in extreme variation in rates of storage loss. Water is becoming an increasingly critical factor in the agricultural and industrial development of Puerto Rico. Reservoir sedimentation is of the utmost importance because of the very limited number of good reservoir sites. Almost invariably the best sites are used first. Development of water storage becomes progressively more expensive as old sites fill up and less desirable sites are utilized. The seasonal character of the rainfall which makes it necessary to store water during the wet season for use during the long, dry season further emphasizes the importance of maintaining dependable storage capacity. The urgent need for agricultural land makes conservation of storage in the irrigation reservoirs an imperative matter. Loss of storage in Guayabal Reservoir located in south central Puerto Rico has already caused a water shortage in part of the South Coast Irrigation District.

Inclusion of the silt factor in the planning and design of storage structures is extremely important. Additional sedimentation studies are needed in Puerto Rico so that adequate allowance can be made for sediment in the design of new structures. Additional studies are also needed to determine sediment sources and to develop means of sediment control.

ACKNOWLEDGEMENT

The author wishes to acknowledge the generous cooperation of the Puerto Rico Department of Agriculture and Commerce in furnishing the funds, equipment, and personnel necessary to make this survey possible. Mr. Angel H. Quintero, Agronomist, in charge of the Caonillas Watershed Management Program, assisted full time during the field survey. Mr. Pablo Valazquez-Walker, Agronomist, devoted most of his time to assisting in the field during the course of the survey. Laborers and other helpers were made available as required.

Mr. L.C.Gottschalk, Research Specialist, Soil Conservation Service, Washington, D.C., assisted in the initial stages of this study and in the field getting the survey under way. Mr. Gottschalk was largely responsible for the methods and techniques used in carrying out the survey and made available much of the specialized equipment used in the field.

Mr. T.C.Green, Director, Caribbean Area, Soil Conservation Service, San Juan, Puerto Rico; Mr. Juan P. Cordova, Supervisory Soil Scientist; and the entire Caribbean Area staff were particularly cooperative and helpful in furnishing technical and administrative assistance, transportation and equipment during all phases of the study. Mr. Florencio Acevedo, Work Unit Conservationist, SCS, Utuado, Puerto Rico, made available all facilities of the work unit office.

Mr. John W. Roehl, Sedimentation Specialist, Soil Conservation Service, Spartanburg, South Carolina, furnished valuable assistance in the sediment volume computations and other phases of the report.

Mr. Jose Vicente-Chandler, Acting Project Supervisor, BPIS&AE Research, Rio Piedras, P. R., made possible the mechanical analysis and volume-weight determinations of the sediment samples and furnished the basic data on soil erodibility.

The District Supervisors of the Caonillas Soil Conservation District were instrumental in securing the funds and assistance necessary for this study.

Most of the photographs used in the report were taken by Antonio Atiles, Agricultural Extension Service, Rio Piedras, Puerto Rico.

Mr. Carl A. Bock, Executive Director, and Mr. Rafael Nevares, Jr., Senior Planning Engineer, Puerto Rico Water Resources Authority, were responsible for furnishing pertinent information on the dam and much of the hydrologic data used in the report.

Equipment used for obtaining sediment samples was borrowed from the Illinois State Water Survey Division, Urbana, Illinois.

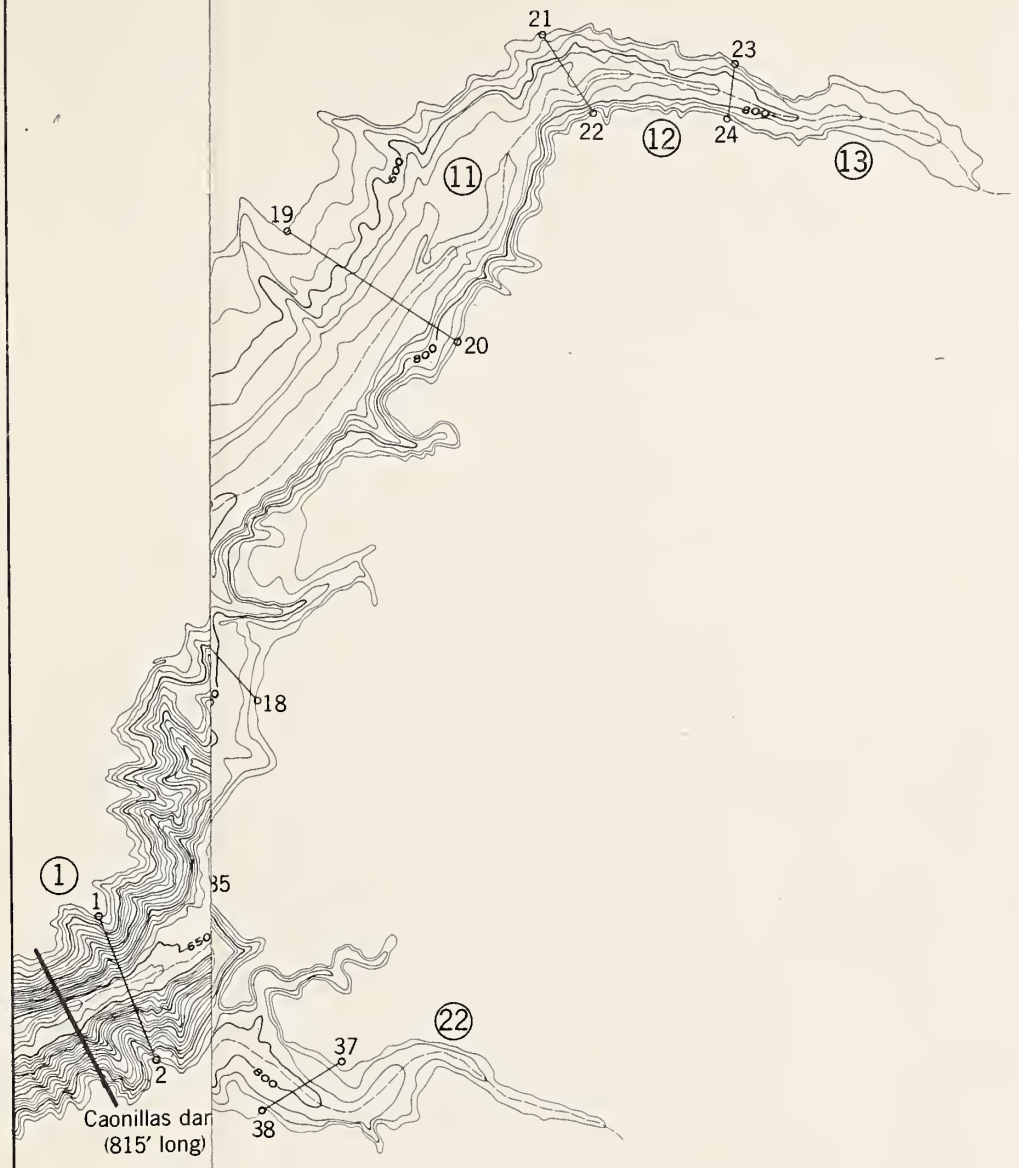
THE RESERVOIR

The Caonillas Hydroelectric Project was developed by the Puerto Rico Water Resources authority as a source of power and to increase storage facilities for the Dos Bocas Hydroelectric Plant located seven and a half miles downstream. Caonillas Reservoir is the largest artificial reservoir in Puerto Rico. It is located on the Caonillas River about 4½ miles east of Utuado. The dam is concrete, straight-gravity, overflow-type structure with a total length of 815 feet along the crest and a maximum height of 250 feet above the stream bed. It is the highest dam in the Island. The elevation of the spillway, including 4-foot flashboards, is 830 feet above mean sea level. Maximum spillway capacity is 107,000 cubic feet per second. Maximum available drawdown is 130 feet. The sluice gate was closed, and the reservoir began to fill on June 28, 1948. A statistical summary of data on the dam is contained in the following tabulation:

CAONILLAS DAM STATISTICAL SUMMARY

Dam

Location...In the west-central part of the Island, on the Caonillas river, about 4½ miles east of the town of Utuado.



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Sedimentation Survey of October 28 to November 19, 1952
Southeastern Region, Soil Conservation Service
in Cooperation with the
Department of Agriculture and Commerce
Commonwealth of PUERTO RICO

0 500 1000 2000 3000 Feet
0 100 200 500 1000 Meters

Contour interval 10 feet

LEGEND

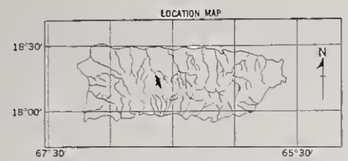
1 ——— 2 Silt Range

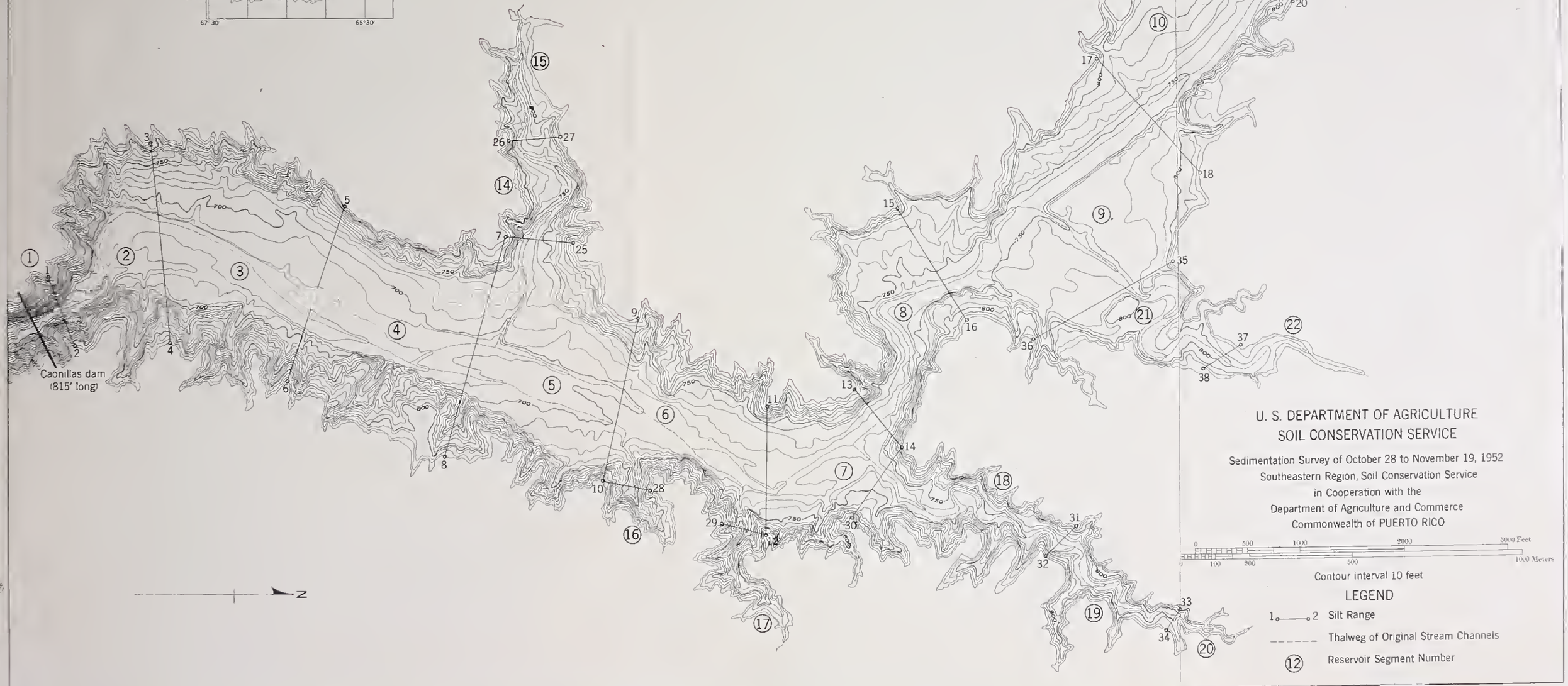
– – – – – – Thalweg of Original Stream Channels

(12) Reservoir Segment Number

CAONILLAS RESERVOIR

CAONILLAS RIVER
UTUADO, PUERTO RICO





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0 500 1000 2000 3000 Feet
0 100 200 500 1000 Meters

Contour interval 10 feet

LEGEND

1 ——— 2 Silt Range

- - - - - - Thalweg of Original Stream Channels

⑫ Reservoir Segment Number

Type and material...Straight-gravity; concrete; non-overflow sections and spillways section.
Foundation...90 percent granite and 10 percent andesite porphyry.

Drainage area (square miles)	48.9
Maximum height, foundation to roadway (feet)	235
Maximum width at base (feet)	195
Total length (feet)	815
Length of spillway (feet)	212
Length of abutment sections (feet)	603
Roadway elevation (feet above mean sea level)	850
Top of parapet elevation (feet abov mean sea level)	854.25
Concrete in dam (cubic yards)	230,000

Work was started on April 17, 1944 and completed in July 1948.

Spillway

Type	Straight overflow with curved apron
Net crest length (feet)	200
Design flood (second feet)	107,000
Crest elevation (feet above mean sea level)	826
Maximum flood head on crest (feet)	26

Reservoir and Water Elevations

Surface area (acres)	678
Length at maximum flood level (miles)	3.25
Elevations (feet above mean sea level)	
Maximum flood	852
Maximum power pool (with flashboards)	830
Maximum power pool	700
Drawdown (feet)	130
Volumes (acre-feet)	
Total at maximum flood level	65,800
Total at maximum power pool	50,149
Total at minimum power pool	2,040
Dead storage	2,040
Usuable storage	48,109
Surcharge storage	15,651

The reservoir formed by the dam is long and narrow with a steep shoreline (fig.1). The lake extends southward from the dam along the Caonillas River for a distance of 3.2 miles. The principal arms of the lake are those formed by Amapola and Felipa Creeks. The surface area at maximum power pool is 678 acres. The original capacity of the reservoir as determined by this survey was 50,149 acre-feet. Capacity-elevation and area-elevation curves for the reservoir are shown in figure 2.

THE SEDIMENTATION SURVEY

Method of Survey

The amount of sediment in the reservoir was determined by direct measurement of sediment thickness. The present capacity was determined by measuring the present water depths at representative points in the reservoir and computing the volume in respect to surface area. A 1/4-inch, cotton-covered, bronze-core tiller rope marked at one-foot intervals was used as a sounding line. Between the one-foot intervals, water depth was estimated to the nearest 0.1 foot. The sounding weight was a bell-shaped, 5-pound, cast-aluminum weight.

The deep sediment deposits in the upper reaches of the lake were measured with a "spud", an instrument developed by the Soil Conservation Service for measuring sediment thickness in reservoirs. It is a 1-inch, case-hardened, sectional-steel rod with cup-shaped grooves at one-tenth-foot intervals. The spud is cast into the lake bed with enough force to penetrate through the sediment deposits into the original valley formation. It is then withdrawn and the thickness of sediment determined by inspection of the material retained in the cups.

The great depth of the lake and the unconsolidated character of sediment deposits made it impractical to use the spud for measuring sediment thickness in the downstream portion of the reservoir. The sediment washed out of the cups as the spud was being retrieved. Where the spud would not work satisfactorily, a 6-foot, 1/4-inch concrete reinforcing rod covered with a layer of concrete was used to determine sediment thickness. It was found that the rough surface of the concrete retained traces of the fine sediment regardless of water depth.

A contour map of the reservoir basin was made for use as a shore-line map, for surface area computations, and for determining sediment thickness in case direct measurement could not be made. This map with a scale of one inch equal to 500 feet[2], was prepared by means of a Kelsh Plotter from aerial photographs taken in 1941 before the reservoir was built. It was found during the survey that all sediment deposits could be measured directly.

The original lake volume and the amount of sediment were determined by the range method of survey. This method consists of laying out a system of representative ranges as nearly parallel as possible. Water and sediment depths were determined along these ranges at sufficiently close intervals for accurate computation of cross-sectional areas.

Concrete posts, with bronze markers imbedded in the top, were set in the ground at each range end. The posts were located within a few feet of crest elevation with about 1-foot of the post exposed above the ground. The range end numbers were stamped on the bronze markers. The elevation of each monument was determined in order to complete the cross-sections above crest elevation. These permanent markers make possible at some later date a comparative study of sedimentation rates by resurveying the same ranges.

A system of 21 ranges was established on the Caonillas Reservoir (fig.1). The range

[2] Map prepared by the Cartographic Division, Soil Conservation Service, Beltsville, Md.

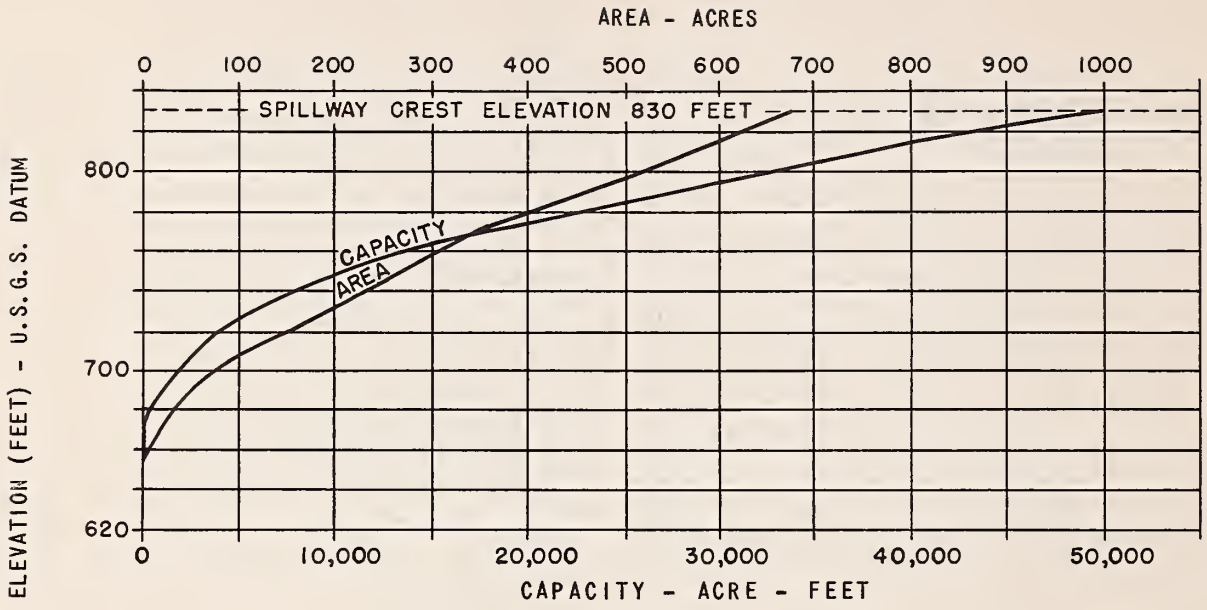


FIGURE 2
CAPACITY - ELEVATION AND AREA - ELEVATION CURVES
CAONILLAS RESERVOIR, PUERTO RICO

ends were located on the aerial photographs by reference to topographic and cultural features. A wire line was fastened between the range end markers when a range was to be surveyed. Distances of soundings from range ends were determined by a line measuring device mounted in the boat. Soundings and silt-thickness determinations were made at regular intervals on each range, usually every 25 or 50 feet.

Storage capacity and sediment volume were computed by the Dobson prismoidal formula[3,4]

$$V=\frac{A'}{3}\left(\frac{E_1+E_2}{W_1+W_2}\right)+\frac{A}{3}\left(\frac{E_1}{W_1}+\frac{E_2}{W_2}\right)+\frac{h_3E_3+h_4E_4+\cdots\cdots}{130680}$$

Where:

V = Original capacity or sediment volume, in acre-feet.

A' = The quadrilateral area, i.e., the area in acres of the quadrilateral formed by connecting the points of range intersection with crest contour between the two principal or most nearly parallel ranges.

A = The lake area of the segment in acres.

E = The cross-sectional area, in square feet, of original capacity or sediment volume cut by a bounding range.

W = Width (length of bounding range) at crest elevation in feet.

h = The perpendicular distance from the range on a tributary to the junction of the tributary with the main stream, or if this junction is outdide the segment, to the point where the thalweg to the tributary intersects the downstream range.

The original and present capacity of the segment next to the dam, which has a vertical face, was computed by the formula:

$$V = A\left(\frac{E}{W}\right)$$

The original and present capacities were computed seperately for each segment and the individual segments totaled to obtain the entire water volume of the reservoir. The difference between the original and present reservoir capacity represented the sediment volume.

Thirty-one sediment samples were obtained for mechanical analysis and volume weight determinations. The sediment sampler consisted of a 1.5-inch diameter pipe with a piston arrangement inside for holding the sediment in the sampler and a messenger device for driving the sampler into sediment deposits at any depth. It was impossible to secure sediment samples in the lower segments because of the light and fluffy character of the deposits.

[3] H.M.Eakin, Silting of Reservoirs, USDA Technical Bulletin No. 524, Revised by C.B.Brown, 1939,U.S.Govt. Printing Office, Washington,D.C.

[4] L.C.Gottschalk, Measurement of Sedimentation in Small Reservoirs, Proceedings American Society of Civil Engineers, Vol. 77, Separate No. 55, January 1951, 33 W. 39th St., New York 18, N.Y.

Figure 3. This sand depasit at a stream entrance has washed fram steep, cultivated slapes in background. The sana will mave farther inta the lake as the lake level recedes. (Agricultural Extensian Service Phato)

Character and Distribution of Sediment

The sediment deposits in the lower segments consist of a thin veneer of loosely compacted dark-gray, fluffy, very fine-textured material. The thickest sediment deposits are in the Caonillas River and Amapola Creek arms of the lake. The maximum depth of sediment deposits found was 5½ feet. Many of the thick deposits are characterized by alternating layers of sand and fine material, the result of successive raising and lowering of the lake level. The old channel deposits are largely sand. The sands are light in color and relatively free from silt and clay. Gas cavities and bubbles indicating rapid organic decomposition were noted in the sediment deposits of the upper reaches.

The distribution of sediment in the upper segments is influenced to a large extent by drawdown of the lake. Drawdown during normal dry season operations may be as much as 80 feet. These extreme fluctuations in lake level have the effect of confining sediment deposits to the deepest parts of the lake. The thickest sediment deposits are located just above normal seasonal drawdown. There are no above-crest delta deposits of any consequence. Delta deposits built up when the lake is near crest tend to move farther down into the lake as the lake level recedes (fig.3). At the time of the survey, drawdown of the lake exposed below-crest sand deposits at many of the stream entrances (fig.4).

Oven-dry weight of the sediment samples varied from 28.1 to 75.5 pounds per cubic foot. The average dry weight of all samples was 38.1 pounds per cubic foot. The average amount of organic matter per sample was 3.02 percent. The samples averaged 30.59 percent sand, 53.85 percent silt, and 15.56 percent clay (table 1).

Figure 5 shows cross-sections of representative ranges. The cross-sections illustrate the narrow, steep-sided character of the reservoir basin. The cross-section of range 9-10 illustrates the small amount of sediment deposited in the downstream portion of the lake.

Figure 4. Drowdown of the loke hos exposed the lorge sond deposit shown in center of photogroph. (Agriculturol Extension Service Photo)

Rates of Sedimentation

A total of 266 acre-feet of sediment had washed into the lake during the 4.3 years of storage, representing an annual storage loss of 61.8 acre-feet. The average annual rate of sediment yield from the watershed above the reservoir is equal to 1.29 acre-feet per year per square mile of drainage area. How this rate of sediment accumulation compares with other reservoirs in Puerto Rico is shown in table 2 below.

The rates of silting determined by this study should be considered the minimum which can be expected under prevailing land use conditions. Runoff records at Caonillas Dam indicate that runoff during the period of storage was somewhat above normal. However, the nine-year period of record at Caonillas is too short to be conclusive. Analysis of much longer records at Dos Bocas and Guineo indicates that during the 4.3-year storage period runoff was about 11 percent below the expected long-term mean.

Sedimentation rates in the future will be considerably modified by the Caonillas Extension Project (fig. 6). This project consists of a series of small head-type dams which divert the headwaters of the Arecibo, Pellejas, and Vivi Rivers into the Caonillas Reservoir through a number of diversion tunnels in tandem. The small reservoirs formed by the diversion dams on the Arecibo, Pallejas, and Vivi Rivers store 500, 200, and 150 acre-feet, respectively. The extension went into operation during October 1952. This project has the effect of increasing the drainage area of Caonillas Reservoir by 35.65 square miles. The Caonillas Extension did not affect the rates of sedimentation as determined by this study. However, any consideration of future rates of storage loss must take into account the enlargement of the net sediment-producing area from 47.9 square miles to 84.55 square miles, an increase of 76.5 percent.

Caonillas Reservoir has an extremely large storage capacity in relation to the amount of runoff and the watershed area. This results in a long detention-storage time which permits practically all suspended

Table 1.--Volume weight and mechanical analysis of sediment samples

Sample No.	Segment	Volume Weight Dry Wt. in Lbs/ Cu.Foot	Mechanical Analysis – Percent								
			Organic Matter	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Total Silt	Total Clay
1	9	33.7	3.65	0.13	0.50	0.91	8.10	14.58	24.22	58.75	17.03
2	9	37.9	2.79	0.11	0.42	0.74	4.12	9.08	14.47	65.73	19.80
3	10	36.4	2.15	3.02	4.60	7.69	17.94	15.88	49.13	41.35	9.52
4	10	58.4	2.90	57.76	9.33	4.43	3.48	3.25	78.25	16.85	4.90
5	11	39.4	2.36	1.90	6.18	14.25	22.70	8.19	53.22	35.66	11.12
6	11	48.4	2.69	4.15	7.72	12.27	15.00	7.62	46.76	40.53	12.71
7	9	43.7	1.72	0.91	2.77	8.74	25.33	15.60	53.35	38.74	7.91
8	9	43.4	1.72	2.23	2.84	8.05	22.48	16.98	52.58	35.95	11.47
9	9	32.6	3.44	0.25	0.73	2.70	8.21	10.00	21.89	58.89	19.22
10	9	39.9	1.78	0.08	0.31	0.79	7.63	25.16	33.97	54.44	11.59
11	8	36.4	1.61	0.30	0.43	1.15	6.52	11.39	19.79	63.69	16.52
12	8	37.0	3.33	0.23	0.72	0.88	7.33	12.65	21.81	61.01	17.18
13	8	34.6	2.79	0.10	0.20	0.29	2.89	7.41	10.89	74.83	14.28
14	9	38.8	2.73	0.23	0.56	2.85	12.10	10.63	26.37	55.78	17.85
15	9	30.4	3.33	0.06	0.27	1.69	7.65	8.82	18.49	61.23	20.28
16	9	33.0	3.65	0.08	0.33	1.13	5.72	6.98	14.24	65.04	20.72
17	9	34.2	4.08	0.11	0.18	0.74	5.14	6.91	13.08	67.82	19.10
18	9	28.1	2.69	0.10	0.36	1.93	13.08	16.85	32.32	53.73	13.95
19	13	30.1	4.41	0.23	0.68	3.16	10.07	10.15	24.29	57.73	17.98
20	9	30.4	3.33	0.09	0.21	1.09	7.49	10.77	19.65	61.10	19.25
21	9	75.5	0.54	38.05	25.67	18.88	8.76	2.03	93.39	5.58	1.03
22	9	38.3	3.12	0.09	0.14	0.42	5.97	10.78	17.40	63.42	19.18
23	9	41.0	3.28	0.23	0.65	2.88	13.27	14.49	31.52	53.37	15.11
24	9	36.0	3.87	0.22	0.65	2.67	10.16	9.91	23.61	59.10	17.29
25	9	37.0	3.55	0.14	0.17	0.66	7.02	12.20	20.19	62.21	17.60
26	10	28.4	4.73	0.09	0.11	0.27	2.08	5.88	8.43	69.83	21.74
27	10	35.2	3.33	0.24	0.81	3.59	9.97	11.23	25.84	57.01	17.15
28	10	33.8	4.30	0.13	0.21	0.41	4.18	7.98	12.91	66.47	20.62
29	10	33.3	2.90	0.21	0.50	1.68	8.27	10.05	20.71	60.34	18.95
30	10	36.9	3.66	1.02	1.82	5.51	13.40	10.52	32.27	52.70	15.03
31	10	39.2	3.12	0.56	2.25	6.97	13.57	9.77	33.12	50.63	16.25
Average		38.1	3.02	3.65	2.33	3.85	9.99	10.77	30.59	53.85	15.56

Note:
1. Organic matter on air dry basis by Dichromate method.
2. Mechanical analysis by pipette method on oven-dried organic matter-free samples.

Table 2.--Comparision of sedimentation of Caonillas Reservoir with other reservoirs in Puerto Rico

		Reservoir			
		Caonillas	Coamo[5]	Comerio[5]	Guayabal[5]
Annual rainfall	Inches	85	45	75	75
Original capacity	Acre-feet	50,149	2,827	4,918	9,580
Watershed area	Square Miles	48.9	48.0	135.0	43.4
Capacity-watershed ratio	Acre-feet/sq.mile	1,026	49	36	221
Age when surveyed	Years	4.3	34.0	21.0	25.0
Total storage loss	Percent	0.5	64.7	68.7	40.6
Annual storage loss	Percent	0.12	1.90	3.27	1.62
Annual rate of sediment Production per square mile of drainage area	Acre-feet	1.29	1.86*	2.38*	3.24*

*An estimate adjusted for trap efficiency of the reservoir.

[5]Rafael Nevares, Jr., and John C. Dunlap, Some Engineering and Geologic Data on Reservoir Silting in Puerto Rico, mimeographed report, San Juan, Puerto Rico, September 1948.

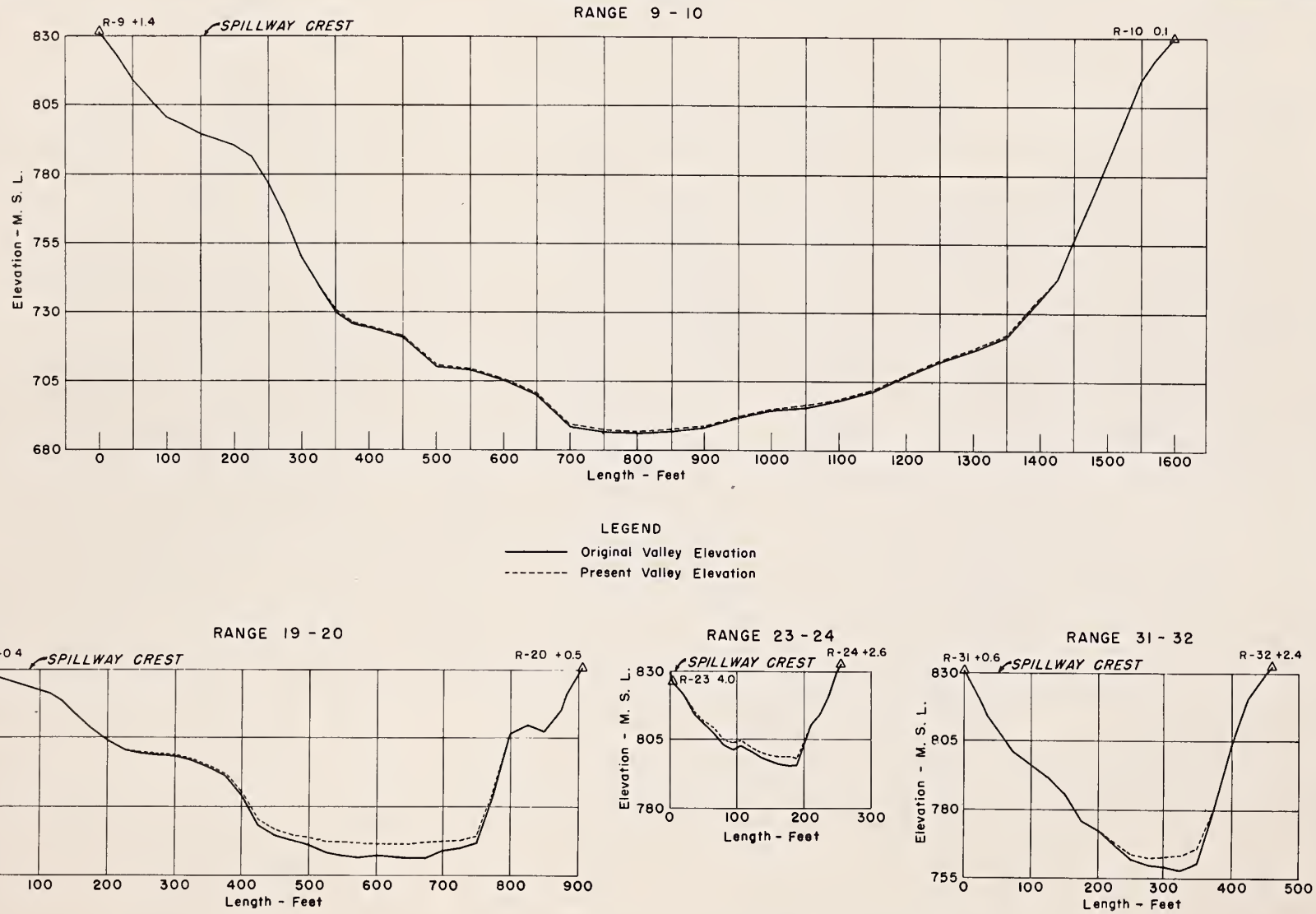
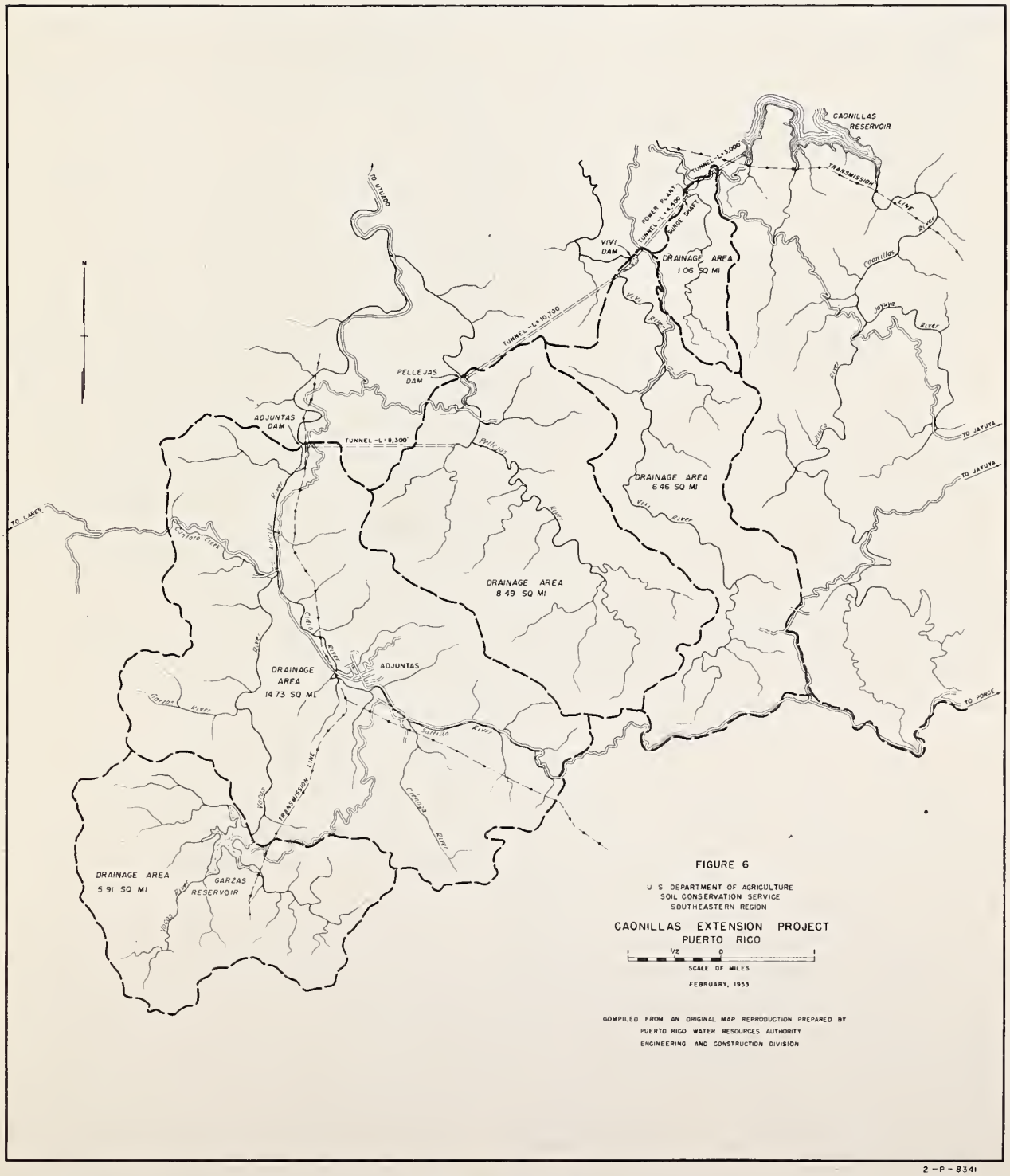


FIG. 5 REPRESENTATIVE RANGE CROSS-SECTIONS - CAONILLAS RESERVOIR, PUERTO RICO

matter to settle out in the reservoir. The amount of water wastage over the spillway is negligible. Trap efficiency, or the ability of the reservoir to retain sediment, is almost 100 percent. The large storage capacity of the reservoir assures a long, useful life for this structure even though the rate of sediment production is relatively high. Assuming that a 60 percent loss of capacity will destroy the storage value of the project, and taking into account the increased watershed area, the reservoir has an expected useful life of 275 years at the present rate of sedimentation. When calculating silting rates with the Extension in effect, the same per-square-mile rate of sediment production was used as was determined for the original watershed.



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A summary of pertinent data relative to Caonillas Reservoir is contained in the following tabulation:

Summary of data on Caonillas Reservoir, Puerto Rico

Age	Years	4.3
Drainage Area[1]		
Without Extension	Square Miles	48.9
With Extension[2]	do	85.5
Reservoir Data		
Area at crest[3]	Acres	678
Storage capacity		
Original	Acre-feet	50,149
Present	do	49,887
Capacity per sq. mi. of drainage area		
Without Extension		
Original	do	1,026
Present	do	1,020
With Extension		
Present	do	583
Sedimentation		
Total volume of sediment	do	266
Average annual sediment accumulation		
Total without Extension	do	61.86
Total with Extension[4]	do	110.30
Per sq. mi. of drainage area[2]	do	1.29
Per acre of drainage area	Cubic feet	87.8
By weight[5]	Tons	1.67
Depletion of Storage Capacity		
Loss of original capacity to date	Percent	0.53
Loss of original capacity per year		
Without Extension	Percent	0.12
With Extension[4]	Percent	0.22

[1]Including lake area.
[2]The Caonillas Extension has increased the drainage area by 36.65 square miles.
[3]Maximum power pool elevation is 830 feet M.S.L.
[4]Assuming the same rate of sediment production per square mile of drainage area as in original watershed.
[5]Based on an average volume-weight of 38.1 pounds per cubic foot.

Cost of Sedimentation

Any realistic appraisal of the cost of sedimentation is difficult because of the many unknown factors involved. A straight-line depreciation of investment provides a basis for computing the minimum annual damage due to sedimentation. The cost of the Caonillas Project was approximately $11,000,000, or $219.35 for every acre-feet of storage. By straight-line depreciation of investment the 61.86 acre-feet of storage lost every year by sedimentation amounts to an annual monetary loss of $13,569. With the increased rate of sedimentation due to inflow from Caonillas Extension, the annual loss of original investment by this method is about $24,000. This is a conservative method of determining average annual damages because it does not take into consideration the loss of service which will accrue as sedimentation of the carry-over storage progresses. Replacement costs presumably will be much higher if less favorable sites are all that remain for future development. Replacement of storage by dredging, if that is the only recourse available, might even be higher.

THE SOIL CONSERVATION SURVEY

A soil conservation survey was made of the entire Caonillas watershed to obtain the basic physical information needed to determine sediment sources and the proper application of soil conservation practices. The land conditions mapped on the survey were soils, slope, erosion, and land use. Aerial photographs, scale 1 inch = 660 feet, were used as a base.[6]

[6] Field work by Rene N. Boothby, Roberto E. Gierbolini, Luis H.Rivera, and Juan Juarez,Jr., Soil Scientists, Soil Conservation Service.

THE WATERSHED

General Description

Caonillas watershed is located in west central Puerto Rico in the municipalities of Jayuya and Utuado. The watershed boundary forms all of the southern and most of the eastern boundary of the municipality of Jayuya. The shape of the watershed is roughly triangular with the apex at the dam. The dam is on the Caonillas River, an important tributary of the Rio Grande de Arecibo. The principal tributary streams are Jayuya, Jauca, and Saliente Rivers. The watershed area is 47.9 square miles, excluding the lake area. The length of the drainage area is 11.4 miles and the average width 4.5 miles.

The climate is mild and uniform, ideal for a year-around growing season. Near the dam the average temperature varies from about 70°F. during the winter months to about 75°F. during the summer. The yearly mean varies from about 73°F. in the lower watershed to 67°F. in the extreme headwaters. The moisture-carrying trade winds are from the east or northeast.

Precipitation

Convectional rains, rains resulting from the condensation of moisture-laden air currents which have been deflected upward, account for most of the rainfall. In general, the higher the elevation the greater the rainfall. The rains are frequently very heavy but are usually of short duration. The amount of precipitation varies greatly within a distance of only a few miles. Mean annual rainfall within the watershed varies from about 60 inches to 110 inches (fig.7)[7]. The average annual precipitation for the watershed is estimated at about 85 inches. Precipitation records show that rainfall is

[7] Miguel A. Quinones, High Intensity Rainfall and Major Floods in Puerto Rico. Paper presented at American Society of Civil Engineers, Inter-American Convention, San Juan, Puerto Rico, November 1952.

FIGURE 7
Precipitation Map of Caonillas Watershed Showing Distribution of Annual Rainfall in inches

Table 3.—Inches of rainfall at selected stations

	Station			
	Caonillas	Guineo	Jauca	Jayuya
Years of Record	8.0	27.0	26.0	6.0
January	5.2	4.3	4.4	4.5
February	4.1	4.2	4.0	4.6
March	2.4	5.0	5.1	1.5
April	7.3	7.4	7.5	4.3
May	10.9	16.9	14.0	7.0
June	4.9	7.7	9.1	2.7
July	4.6	7.0	9.9	3.0
August	9.4	12.2	15.1	6.4
September	9.4	14.0	16.1	6.9
October	8.7	16.3	15.8	6.3
November	5.0	8.5	8.9	4.4
December	4.2	4.9	4.6	4.3
Annual	76.1	108.4	114.5	55.9

highest during May, August, September, and October; lowest during November through April (table 3). The heavest rains occur during the summer months.

Although rainfall is relatively high over the entire watershed, high temperatures, rapid evaporation, low relative humidity, and almost constant air movement all combine to decrease its effectiveness. It is estimated that effective rainfall is equivalent to from 50 to 70 percent of an equal amount of rain occuring in the United States.

The passage of tropical hurricanes, which occur on an average of about once every five years, causes heavy precipitation for several hours or several days of intermittent rain. The torrential rains which accompany these storms cause destructive soil erosion and serious sedimentation. Maximums of from 12 to 22 inches of rain in 24 hours were recorded in the watershed during the storm of September 1928, one of the most severe of record.

Runoff

Average runoff from the entire drainage area is about 34 inches per year. In the high-rainfall areas of the extreme headwaters runoff is estimated at 85 inches per year.

Figure 8. The steep-sided, V-shaped valleys have little or no alluvial development. Streambeds are usually strewn with gravel and large boulders: (Soil Conservation Service Photo)

Topography

The relief is rugged, mountainous, and marked by high peaks in the extreme headwaters. Elevation ranges from 615 feet at the base of the dam to 4,390 feet on Cerro de Punta, the highest point in Puerto Rico. The area is deeply dissected by a dense, dendritic drainage system of high-gradient streams -- topographic features which contribute to a very effecient system for transporting sediment from its source to the reservoir. The topography is characterized by knife-edged, steep-sided ridges. The deep, V-shaped valleys are narrow and have little or no alluvial development (fig.8). Stream gradient is controlled by rock-ledge channels. Streambeds are usually strewn with large boulders. Streambanks are generally low and poorly developed

Geology

The watershed is situated in the complex mountain section of the interior. About 60 percent of the area is underlain by granitic rocks. The warm, humid climate has resulted in very deep weathering of the granites which may extend downward for several hundred feet. The granites give rise to granular, light to medium-textured soils which erode very rapidly on the steep, cultivated slopes.

Volcanic rocks, largely made up of tuffs and shales of andesitic composition with some igneous intrusives underlie the eastern and southern rim of the watershed. The tuffs and shales are generally fine grained and have a low silica content. The soils developed from them are high in clay. Weathering usually does not extend much below 50 feet.

Soils

The soils belong to the podzolic, latosol, and lithosol soil groups. Temperature and relief are much the same over the area and major differences in soil characteristic are largely the result of differences in parent material and amounts of rainfall. Soils derived from granite cover all of the central and western part of the watershed. These light to medium-textured soils are very susceptible to erosion and are the most intensively cultivated soils in the watershed.

The soils along the northern, eastern, and southern rim of the watershed are predominantly medium to heavy-textured, and red to purple in color. Weathering of the fine-grained tuff and other volcanic rocks from which these soils are derived has produced soils high in permeable clay, medium low in silt, and low in sand. They are high in iron and aluminum and low in silica. The relief is mountainous and rainfall is high. A high percentage of the soils at the higher elevations is very stony, wet from continuous rainfall, and classed as non-agricultural.

The soils were grouped according to characteristics significant in conservation planning. The most important of these characteristics were effective depth, texture, permeability, parent material, thickness, and drainage. The locations of the soil groups are shown in figure 9. The soil group acreages are shown in table 4.

Table 4.--Distribution of Soil Groups

Soil Group	Acres	Percent
1	15,264	49.8
2	2,876	9.4
3	3,866	12.6
4	1,180	3.9
5	2,716	8.9
6	3,500	11.4
7	1,041	3.4
Miscellaneous	185	0.6
TOTAL	30,628	100.0

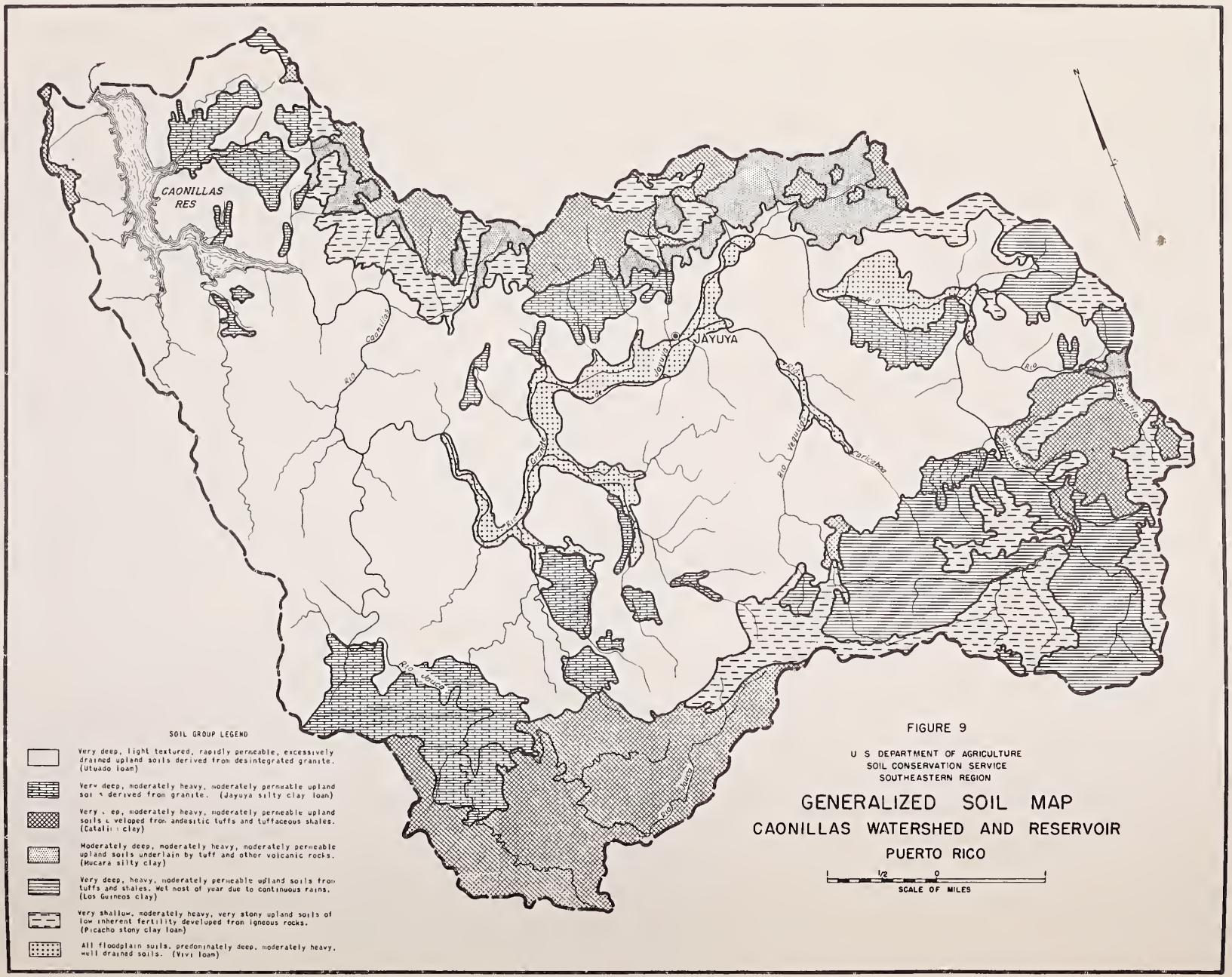
Each soil group is described briefly below:

Group 1 is the most extensive soil group, occupying about half of the watershed. It is the most important group from the standpoint of erosion, amount of land in cultivation, and sediment production. The soils are very deep, light-textured, rapidly permeable, excessively drained upland soils developed from deeply weathered granite. There is very little soil profile development. The soils are moderately productive, easily worked, and well adapted to production of tobacco and subsistence crops. Relief is characterized by numerous drainageways, steep, short slopes and very narrow ridge tops. Average slope is 52 percent. Sheet erosion is very active. Utuado loam is the most extensive soil series and typifies the group.

Group 2 soils represent 9.4 percent of the drainage area. The soils are very deep, moderately heavy, moderately permeable, well-drained red soils derived from granite. Sheet erosion is moderate to severe. Jayuya silty clay loam is the predominant series.

Group 3 soils are very deep, moderately heavy, moderately premeable, well-drained soils derived from andesitic tuffs and tuffaceous shales. These are lateritic soils high in clay and brownish-red to purple in color. They usually occur at high elevations where annual precipitation is 80 inches or more. The soils are highly productive for a wide variety of crops. Catalina clay is the most common soil series. This group occupies 12.6 percent of the watershed.

Group 4 soils are moderately deep, moderately heavy, moderately permeable, well-drained soils developed from tuffaceous rocks. The most representative series is Mucara silty clay. Slopes are generally very steep and there is very little cultivation. Most of the land is in coffee. These soils


CAONILLAS RES
JAYUYA
Río Caonillas
Río Jayuya
Río Yayuya
Río Saliente
Río Yayuya
Río Yayuya
N
SOIL GROUP LEGEND
Very deep, light textured, rapidly permeable, excessively drained upland soils derived from desintegrated granite. (Utuado loam)
Very deep, moderately heavy, moderately permeable upland soils derived from granite. (Jayuya silty clay loam)
Very deep, moderately heavy, moderately permeable upland soils developed from andesitic tuffs and tuffaceous shales. (Catalina clay)
Moderately deep, moderately heavy, moderately permeable upland soils underlain by tuff and other volcanic rocks. (Hucara silty clay)
Very deep, heavy, moderately permeable upland soils from tuffs and shales. Wet most of year due to continuous rains. (Los Guineos clay)
Very shallow, moderately heavy, very stony upland soils of low inherent fertility developed from igneous rocks. (Picacho stony clay loan)
All floodplain soils, predominately deep, moderately heavy, well drained soils. (Vivi loam)
FIGURE 9
U S DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
SOUTHEASTERN REGION
GENERALIZED SOIL MAP
CAONILLAS WATERSHED AND RESERVOIR
PUERTO RICO
1/2 0
SCALE OF MILES

occupy 3.9 percent of the watershed.

Group 5 soils are very deep, heavy, moderately permeable soils developed from andesitic tuffs and tuffaceous shales at high elevations having heavy rainfall. The soils are wet most of the year because of frequent rains. The relief is mountainous. This group occupies 8.9 percent of the watershed and is almost entirely in forest. Los Guineos clay is the most common series.

Group 6 soils are very shallow, moderately heavy, and very stony, with very low inherent fertility. The parent material is mostly igneous rocks of andesitic composition with some hardened shales and conglomerates. This group repersents 11.4 percent of the watershed and is almost entirely non-agricultural.

Group 7 includes all alluvial soils and riverwash located along the larger streams. The floodplain soils are predoninantly well drained and productive. They represent 3.4 percent of the watershed.

Slope

Slopes are generally very steep in the rugged, mountainous, highly dissected interior section in which the watershed is located. Increased population and the need for additional land has brought steeper and steeper land into cultivation. In most cases the cultivated slopes are too steep to permit the use of agricultural machinery or even draft animals. Most farming operations are done by hand (fig.10). The average slope for all lands is 50.3 percent. Acreage of land slope classes are shown in table 5.

Table 5.--Distribution of land slope classes

Slope Class	Acres	Precent
A slopes, 0-3 percent	456	1.5
B slopes, 3-12 percent	748	2.4
C slopes, 12-20 percent	507	1.7
D slopes, 20-40 percent	3,706	12.1
E slopes, 40-60 percent	18,881	61.6
F slopes, 60 percent and over	6,145	20.1
Miscellaneous	185	0.4
TOTAL	30,628	100.0

Figure 10. Most cultivotion is done by hond os the slopes ore too steep for ogriculturol mochinery. Slopes in this tobocco field voried from 70 to 120 percent. The borriers of vegetotive debris shown in the bockground do not give effective protection from erosion on slopes this steep. (Agriculturol Extension Service Photo)

Erosion

Sheet erosion is the principal source of sediment. The unusually steep slopes make all lands not protected by good vegetative cover very susceptible to destructive sheet erosion. Soil losses from tobacco fields and other clean-tilled crops are very high. Erosion experiments on Group 1 soils indicated that on 60-percent slopes about 70 percent of the total soil loss was the direct result of mechanical erosion — soil lost by rolling down the slope when disturbed by cultivation practices. Erosion on these soils is accelerated also by the practice of ditching steep tobacco fields to facilitate the removal of surface water. (See fig.11). Erosion has affected all but 2 percent of the watershed. More than 93 percent of the area is classed as having moderately severe to severe sheet erosion (table 6). There is no gully erosion. Serious and widespread sheet erosion is believed to be a relatively recent development very closely associated with the increased acreage of tobacco and other clean-tilled crops

Table 6.--Distribution of erosion classes

Erosion Class	Acres	Percent
Recent alluvial or colluvial Deposits	19	0.1
0 No apparent erosion	576	1.9
1 Slight sheet erosion	380	1.2
2 Moderate sheet erosion	831	2.7
3 Moderately severe sheet erosion	25,486	83.2
4 Severe sheet erosion	3,127	10.2
5 Very severe sheet erosion	24	0.1
Miscellaneous	185	0.6
TOTAL	30,628	100.0

Erosion on roadway cut and fill slopes is not an important source of sediment. Fill slopes are well protected by native vegetation. Most of the cut slopes are through weathered granite which has a tendency to form a relatively stable protective glaze over the exposed surface.

Streambank erosion is negligible. Channels are on bedrock and are not a source

Figure 11. The practice of ditching tobacco fields, as shown in right foreground, increase soil erosion. The mountainous and semi-mountainous area in the background is typical of most of the coffee lands. (Agricultural Extension Service Photo)

Table 7.--Distribution of land use classes

Land use	Acres	Percent
Cultivated land		
Clean-tilled crops, largely tobacco	1,016	3.3
Sugar cane	1,542	5.0
Forage grasses	35	0.1
Pasture		
Improved -- good clover	143	0.5
Unimproved -- native grasses	11,248	36.7
Brushy pasture	23	0.1
Coffee land	8,042	26.3
Forest		
Forest -- large trees	365	1.2
Abandoned coffee land	3	0.0
Brushy land	8,019	26.2
Idle land	7	0.0
Miscellaneous	185	0.6
TOTAL	30,628	100.0

of any appreciable amount of sediment. The channels generally are poorly developed with low banks and strewn with boulders.

Land Use

Originally the watershed was covered by a dense, tropical forest. The Indians living in the area had developed a primitive type of agriculture but it is doubtful if enough land was cultivated to increase the rate of erosion much above the geologic norm. The early Spanish settlers were not farmers or interested in farming. There was very little agricultural development or real settlement during the first 250 years of Spanish occupancy.[8]

The earliest agricultural development was the pasturing of cattle along the river bottoms and the more level uplands. Coffee was introduced from Haiti in 1736. By 1900 large coffee haciendas were well established in the watershed and had largely supplanted the last remaining virgin forest. Coffee was the most important crop in 1898 although the acreage of pasture was several times larger. The hurricane of 1898 destroyed most of the coffee plantings. Much of the land was replanted to coffee, but this hurricane marked the beginning of the trend toward tobacco and small crops. The hurricane of September 1928 almost wiped out the coffee plantations again. Coffee is still grown extensively in the watershed but has gradually been supplanted in importance but not in acreage by tobacco and other crops.

The coffee farm is typically a large farm of coffee bush and shade trees broken by pasture, small areas of other crops, and uncultivated forest and bush land. Tobacco farms, though more numerous, occupy less than one-fourth of the area occupied by coffee farms. About 75 percent of the coffee farms and half of the tobacco farms are owner-operated. Many of the tobacco and minor crop farms are share-cropped.

The acreage of tobacco increased rapidly between 1900 and 1930. Since 1930 the acreage has declined somewhat. Other crops have replaced tobacco on some farms. Tobacco produces quick returns, requires a large amount of labor per acre, and is adaptable to slopes too steep for anything but hand cultivation. The steep, well-drained, medium to light-textured soils which predominate in the central portion of the watershed are well adapted to tobacco production (see fig.12).

Tobacco farming favors small holdings. The size of farms has been decreasing during the past 50 years, a trend considerably influenced by the increase in tobacco farming. Approximately half of the farms in the watershed are 5 cuerdas[9] or less in area; 25 percent have from 6 to 14 cuerdas; 12 percent have 15 to 29 cuerdas; 9 percent have from 30 to 100 cuerdas; and 4 percent have 100 or more cuerdas.

Pasture land occupies 37.3 percent of the watershed; forest 27.4 percent; coffee trees 26.3 percent; and cultivated land 8.4 percent. Table 7 shows the acreage in each land use.

Population

The total population of the watershed is about 15,000, a population density of 307 persons per square mile. Population density is high when compared with the United States, but is relative low when compared with the average density figure of 646 persons per square mile for all of Puerto Rico (1950 census). The rural population density is

[8] Luther H. Gulick, Jr., Rural Occupance in Utuado and Jayuya Municipios, Puerto Rico, Research Paper No. 23, University of Chicago, Chicago, Ill., June 1952.

[9] One cuerda = 0.9712 acres.

Figure 12. Aerial view of typicol tobacco fields. (Agricultural Extension Service Photo)

about 275 persons per square mile as compared to the Island rural average of 410 persons per square mile.

The dense population has a direct bearing on the problems of soil conservation. The constantly increasing number of people dependent on agriculture for a living has brought more and more land into cultivation. The only new lands available for cultivation are the steep, less desirable areas which are difficult or impossible to protect from the destructive effects of erosion (fig.13). Pressure for more land and more income has already led to the cutting of most of the woodlands.

Source of Sediment

The physical characteristics of the watershed are such that most of the eroded material is washed directly from the hillsides into well-defined drainage channels where it becomes part of the stream sediment load (see fig.14). Many slopes are steep enough to approach the angle of repose so that once soil is detached it moves to the base of the slope. Except along some of the larger streams the steep-sided drainageways lack any colluvial or alluvial development. There are no well-developed alluvial fans. In the granitic part of the watershed, the dense pattern of high-gradient drainageways forms an extremely efficient system for transporting sediment from its source to the reservoir. Stream channels are clear of sand and mud bars, indicating that the streams are able to transport all sediment contributed to them.

A limited amount of experimental data on erosion losses under different soil and land use conditions was available from plots located at Mayaguez and Utuado. This material was used as a basis for estimating the average annual rate of soil loss due to erosion. Group 4 soils are the most erodible, but occupy only about 4 percent of the watershed. Half of the total amount of soil lost by erosion comes from Group 1 soils. Erosion results in an estimated annual soil loss of 61,800 tons of soil. The average amount of sediment deposited in the lake every year was 51,250 tons, or about 83 percent of the total

Figure 13. Slopes vary from 70 to 95 percent in this bean field. Production cannot be maintained on slopes this steep. (Agricultural Extension Service Photo)

amount of soil lost by erosion.

Coffee lands, which cover 26.3 percent of the watershed, accounted for 40.5 percent of the total soil loss. Clean-tilled crops, which occupy only 3.3 percent of the total land area, cause 22.8 percent of the soil loss. Unimproved pasture lands, occupying 36.7 percent of the watershed area, produced 21.2 percent of the total soil loss. Brushy forest lands account for 13.8 percent of the erosion losses (table 8).

Land Capability Classes

In order to determine the extent to which land was in proper use and as a further clue to sediment sources, the lands in the watershed were classed according to use capability — a classification of the different kinds of land according to those properties that determine the ability of the land to produce permanently with a minimum of soil loss. Brief descriptions of the seven land classes occurring in the watershed are given in table 9.

The distribution of land use within each land capability class is shown in table 10. The 1,232 acres of cultivated land within Land Capability Class IV are the source of a considerable portion of the soil lost by erosion. Class IV lands can be safely used for cultivation only with severe limitations. There are 284 cultivated acres in Land Classes VI and VII. These classes are not recommended for cultivation. They should be in continuous vegetation. Land Capability Classes IV, VI, and VII account for 86.6 percent of the total area.

Figure 14. View of small watershed entirely in tobacco. Soil is washed directly from hillsides into drainage channels. (Agricultural Extension Service Photo)

Table 8.--Estimated soil losses from erosion expressed as percent of total soil loss

Land Use	Soil Groups 1	Soil Groups 2,3,5,6	Soil Groups 4	Total
	Percent	Percent	Percent	Percent
Cultivated Land				
Clean-tilled crops (largely tobacco)	15.1	6.4	1.3	22.8
Sugar cane	1.2	0.4	0.0	1.6
Forage grasses	0.0	0.0	0.0	0.0
Total	16.3	6.8	1.3	24.4
Pasture				
Improved pasture	0.0	0.0	0.0	0.0
Unimproved pasture	14.7	5.4	1.1	21.2
Brushy pasture	0.0	0.0	0.0	0.0
Total	14.7	5.4	1.1	21.2
Coffee	16.8	19.0	4.7	40.5
Forest				
Forest -- large trees	0.0	0.1	0.0	0.1
Abandoned forest	0.0	0.0	0.0	0.0
Brushy land	2.2	11.2	0.4	13.8
Total	2.2	11.3	0.4	13.9
TOTAL	50.0	42.5	7.5	100.0

Table 9.--Definition of land capability classes

Land Capability Class	Major Land Use Suitability	Description and Limitations	General Recommendations: Cultivated (Percent)	General Recommendations: Cover (Percent)
I	Land Suited for Cultivation	Very good land. Level to nearly level bottomland suitable for continuous cultivation with few limitations	100	
II	Land Suited for Cultivation	Good land. Gently sloping lands with slight to moderate erosion. Moderate limitations.	50	50
III	Land Suited for Cultivation	Moderately good land. Sloping uplands with moderate to severe erosion. It is subject to severe limitations in use for crop production. Regular crop use possible where properly treated.	33-1/3	66-2/3
IV	Land Suited for Cultivation	Steep land suitable for occasional cultivation with severe limitations. It is fairly good land best maintained by keeping in perennial vegetation	25	75
VI	Land Not Suited For Cultivation	Steep lands requiring continuous vegetation. Suited to trees, coffee or pasture if carefully managed.	—	—
VII	Land Not Suited For Cultivation	Lands either steep, shallow, stony, very severly eroded or wet most of year from frequent rains. Best suited to woodland.	—	100
VIII	Land Not Suited For Cultivation	Lands not suited for agricultural use. Coarse sand and gravel-riverwash.	—	—

Table 10.--Land use by land capability classes

Land Use	Land Capability Class I	II	III	IV	VI	VII	VIII	Misc.	Total
	Acres	Acres	Acres	Acres	Acres	Acres	Acres	Acres	Acres
Cultivated land									
L - Clean-tilled crops	52	19	282	500	138	24	1		1,016
L_1 - Sugar cane	435	49	215	730	102	11	–		1,542
L_2 - Forage grasses	5	5	13	2	9	–	1		35
Total	492	73	510	1,232	249	35	2		2,593
Pasture									
P - Improved, good cover	5	12	19	80	14	13			143
P_1 - Unimproved, native grasses	167	85	1,269	7,082	748	1,751	146		11,248
P_2 - Brushy pasture	–	–	–	–	–	3	20		23
Total	172	97	1,288	7,162	762	1,767	166		11,414
Coffee land Total	80	2	887	4,785	1,338	950	–		8,042
Forest									
F - Forest	–	–	–	17	–	348	–		365
F_1 - Abandoned woodland	–	–	2	–	–	1	–		3
F_2 - Brushy land	3	1	74	1,474	64	6,350	53		8,019
Total	3	1	76	1,491	64	6,699	53		8,387
Idle land Total	–	–	–	1	–	–	6		7
Miscellaneous									
Urban, etc. Total	–	–	–	–	–	–	–		86
Rivers Total	–	–	–	–	–	–	–		99
Total sediment contributing area	747	173	2,761	14,671	2,413	9,451	227	18.5	30,628
Percent of total	2.4	0.6	9.0	47.9	7.8	30.9	0.8	0.6	100

RECOMMENDATION FOR WATERSHED TREATMENT

Conservation Practices and Needs

Proper land-treatment measures offer the best solution to the sedimentation problem of Caonillas Reservoir, since the sediment moving into the reservoir is almost entirely a product of sheet erosion on agricultural lands. To be most effective the conservation program should include the entire watershed. Every acre should be put to the use which will insure a minimum soil loss with maximum financial return.

Virtually all cultivated upland areas are steep enough to require intensive conservation treatment. The conservation measures needed on these lands should include conversions to less intensive use, improved rotations, contour cultivation, strip cropping, crop residue management, vegetative or rock barriers, complete water-disposal systems, and proper fertilizing and liming.

The watershed is particularly well adapted to the production of grass. Good grass cover offers excellent protection from erosion. Grassland farming should be emphasized and pastures should be improved by reseeding with better varieties of grass, by liming and fertilizing, and by controlled grazing.

Coffee lands are the principal source of soil loss by erosion, but if properly handled, an important reduction can be effected in the rate of sedimentation. Coffee land can be improved by maintenance of ground cover, by making provisions for water disposal, and by construction of individual-tree terraces.

The area in forest should be increased. Selective cutting with good woodland management practices will increase the protection afforded by forest areas.

Special measures should include the planting of coffee or close-growing plants such as bamboo or Cana-Castilla at the bottoms of steep draws.

Effect of Program

A very substantial reduction in the rate of sedimentation can be achieved by a sound conservation program. Experimental plot data on coffee land show erosion losses only one-tenth as high with good conservation practices as with prevailing practices. It is estimates that an 80 percent reduction in erosion losses can be brought about by a complete conservation program. The most significant reductions in soil loss can be made on the clean-tilled and coffee lands.

Caonillas Watershed Management Program

The seriousness of the erosion problem and its effect on sedimentation in the reservoir has been recognized and steps have already been taken toward minimizing the damage.

The Secretary of Agriculture and Commerce determined that funds allotted to the Insular Soil Conservation Committee should be spent in a specific problem area where results would be clearly evident and could serve as a guide for similar programs elsewhere. The Caonillas Valley was selected as the most suitable location for beginning this study.

In August 1950, the Secretary called a conference of representatives from interested Insular and Federal agencies to determine the extent to which their activities could be coordinated in a comprehensive watershed improvement program. A committee known as the Caonillas Valley Committee was appointed by the Secretary to study specific needs for a comprehensive program and to determine the part each agency should take in carring out the work. Following recommendations of the Committee, the Insular Government appropriated $30,000 to begin the project. At present there is an agronomist in charge of the program, with two assistant agronomists.

The watershed is located in the Caonillas Soil Conservation District, which has available the technical assistance of the Soil Conservation Service employees assigned to the District. The District Supervisors assisted in soliciting funds and formulating plans for carrying out the program.

The watershed management project is directed primarily toward an intensified program of soil and water conservation. However, the plan is much more comprehensive and provides for the participation of all Insular and Federal agencies active in the area.

The principal needs in the watershed are for the additional funds and personnel necessary to carry out a complete and comprehensive soil and water conservation program on the entire watershed, including the Caonillas Extension. All phases of the program should be directed toward securing maximum cooperation of the landowners.

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